# THE NEW INJECTION REGION OF THE CERN PS BOOSTER

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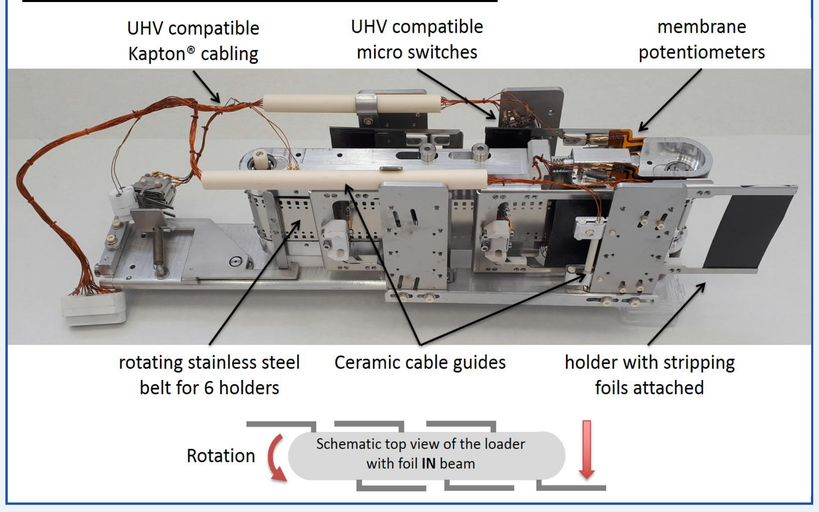
## ABSTRACT

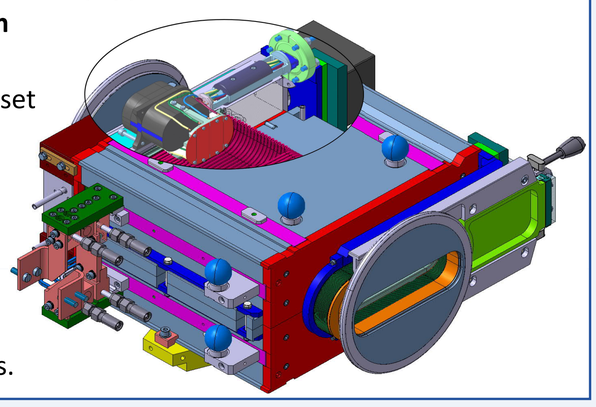
During the Long Shutdown 2 (LS2) at CERN, the new Linac4 (L4) accelerator will be connected to the PS Booster (PSB) to inject 160 MeV $H^-$ beam into the 4 superposed PSB rings. In order to achieve this, we have designed, built and pre-assembled a completely new $H^-$ charge-exchange injection chicane system, with a carbon stripping foil unit to convert the negative hydrogen ions into protons by stripping off the electrons. In parallel, we have built and installed a test stand in the L4 transfer line enabling us to gain valuable experience with operation of the stripping foil system and to evaluate different foil types during the L4 reliability runs. This paper describes the final design of the new PSB injection region and reports on the important test results obtained with the stripping foil test stand.

## FOIL EXCHANGE MECHANISM



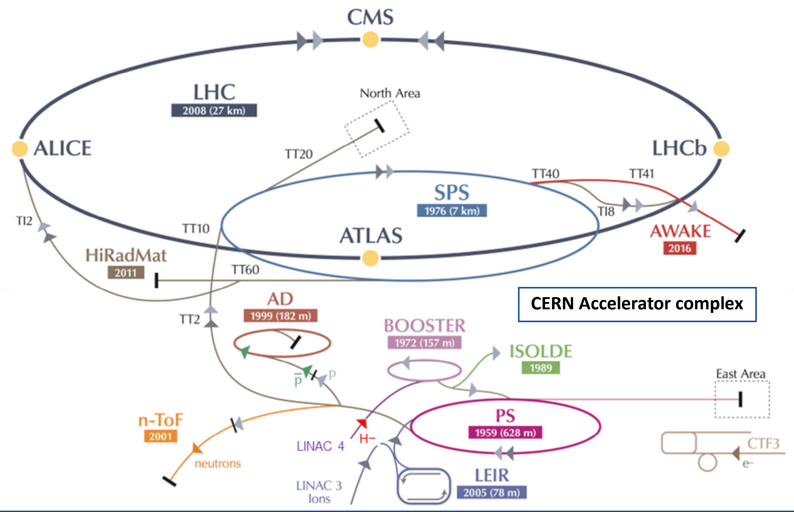

## INSTRUMENTATION

Each BSW4 magnet is equipped with an internal, in-vacuum, Titanium **$H^0/H^-$ beam dump**. These are equipped with a set of 4 Titanium plates, designed to measure the amount and the position of the residual $H^0$ and $H^-$ beam currents.



## INTRODUCTION

**LHC Injectors Upgrade** (LIU) Project has the aim of producing the challenging **High Luminosity LHC** (HL-LHC) beam parameters and comprises a new **160 MeV $H^-$** linear accelerator, so-called **Linac4**, as well as major upgrades and renovations of the Proton Synchrotron Booster (PSB), the Proton Synchrotron (PS) and the Super Proton Synchrotron (SPS).

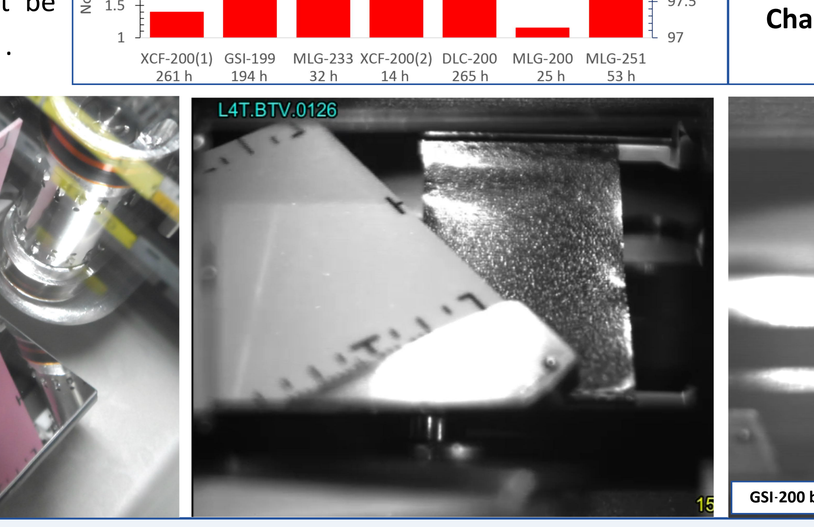



## PAINTING BUMP

There are **2 types** of **KSW** magnets; the inner- (2L1 & 16L1), and the outer-magnets (1L4 & 16L4). The magnet are all **individually powered** with **slightly different kick strength**.

| Parameter | Unit | 1L4 | 2L1 | 16L1 | 16L4 |
|---|---|---|---|---|---|
| Kick | mrad | 1.15 | 5.41 | 5.85 | 0.83 |
| Magnetic field | mT | 6 | 28 | 30 | 4 |
| Gap height | mm | 132 | 132 | 132 | 132 |
| Gap with | mm | 132 | 132 | 132 | 132 |
| Length | mm | 370 | 370 | 370 | 370 |
| Inductance | µH | 390 | 39 | 39 | 390 |
| Number of turns | | 48 | 16 | 16 | 48 |
| Repetition rate | Hz | 1.1 | 1.1 | 1.1 | 1.1 |

**Main KSW Magnet Parameter**

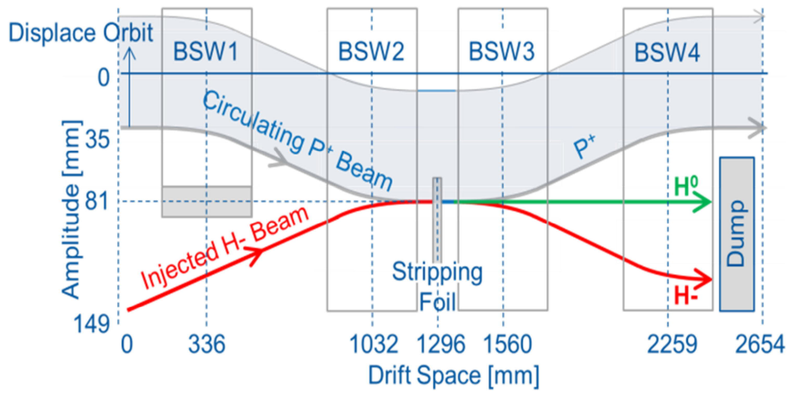



**KSW Current Waveforms**

**LHC (High Brightness):** *Small emittance*, 45-50µs plateau, beam quickly away from foil to reduces emittance blow up.

**ISOLDE (High Intensity):** *Large emittance*, initial decay for bunch core → mitigation of space charge effects, long plateau to paint outer region, limited by the150µs BI.DIS pulse.

## $H^-$ CHARGE-EXCHANGE INJECTION




The local orbit of the PSB beam is displaced horizontally by ~81 mm using **two independent closed orbit bump** systems:

1. The **Painting Bump**, 4 KSW kickers outside the injection region, give a 35 mm closed orbit bump, with falling amplitude.
2. The **Injection Chicane**, a set of 4 dipole magnets (BSW).

A **stripping foil** will convert ~98% of the $H^-$ into protons by stripping off the electrons. Partially stripped $H^0$ and ~1% $H^-$ missing the foil are directed to an **internal $H^0/H^-$ dump** located in chicane magnet BSW4.

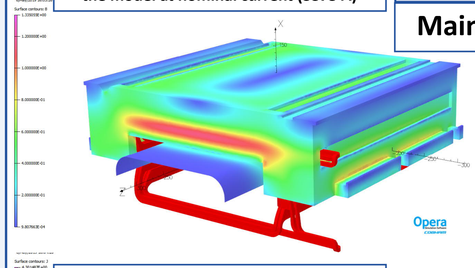
## INJECTION CHICANE

Each of the 4 PSB rings has **1 septum magnet (BSW1)**, providing a field free region for the injected $H^-$ beam, and **3 bumper magnets.**

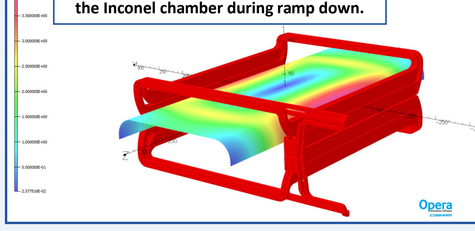
| Parameter | Unit | BSW1 | BSW2-4 |
|---|---|---|---|
| $\int B_y dl$ at magnet center | m.Tm | 126 | 126 |
| Electric peak current | kA | 6.7 | 3.4 |
| RMS current | A | 463 | 231 |
| Resistance | mΩ | 3.5 | 7 |
| Inductance | µH | 13 | 77 |
| Number of turns | | 4 | 8 |
| Endplate thickness | mm | 13.6 | 12 |
| Aperture HxV | mm | 162x85 | 242x85 |
| Good field region 1% | mm | 140x85 | 220x85 |

**Main BSW Magnet Parameter**

**Magnetic Flux density [T] on the surface of the model at nominal current (3375 A)**




**Maximum current density on the surface of the Inconel chamber during ramp down.**

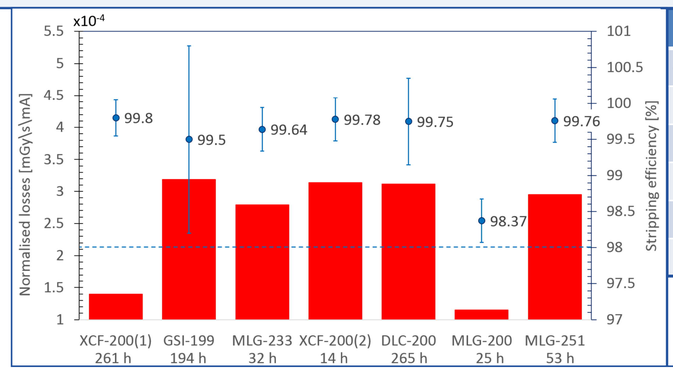



**During injection**, the magnets are powered and the $H^-$ beam is injected into the PSB at the flat-top.

**After injection**, within 5 ms the chicane is linearly ramped down.

## STRIPPING FOIL EFFICIENCY

Dedicated L4 runs took place to determine the stripping efficiency, which was above the theoretical value of >99%, except the MLG-200, as expected for multi-layer graphene foils. Since Graphene foils have interesting mechanical properties, thicker foils were tested (MLG-233 and MLG-251). Unfortunately the emittance blowup could not be measured with the test set-up, having only a single beam passage .



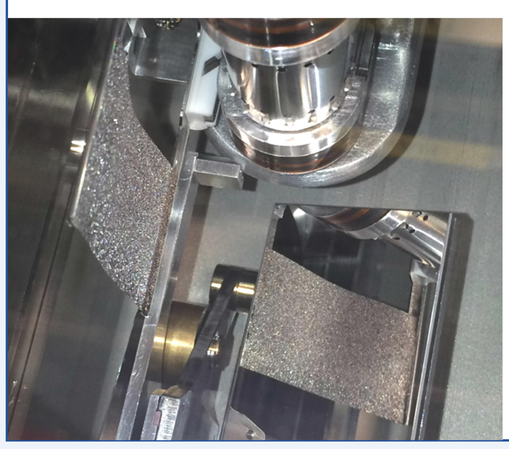

| Description | Weight | Reference |
|---|---|---|
| Amorphous Carbon | 200 µg/cm$^2$ | XCF-200 |
| Amorphous Carbon | 199 µg/cm$^2$ | GSI-199 |
| Diamond-like Carbon | 200 µg/cm$^2$ | DLC-200 |
| Multilayer Graphene | 200 µg/cm$^2$ | MLG-200 |
| Multilayer Graphene | 233 µg/cm$^2$ | MLG-233 |
| Multilayer Graphene | 251 µg/cm$^2$ | MLG-251 |

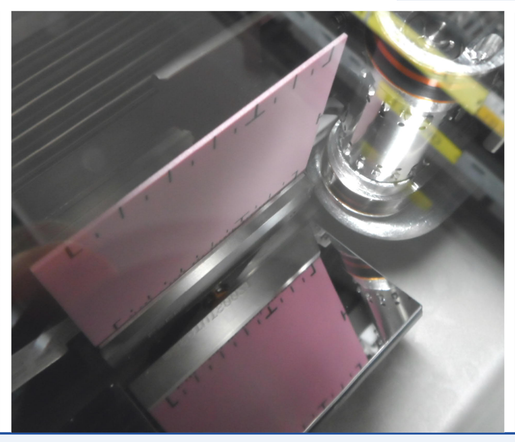
**Characteristics of the different foil types tested**

| Parameter | Unit | Value |
|---|---|---|
| Ion Species | | $H^-$ |
| Output energy | MeV | 160 |
| Repetition rate | s | 1.2 |
| Beam pulse length | µs | 200-600* |
| Mean pulse current | mA | 5-20 |
| Transverse emittance | π µm (rms) | 0.4 |

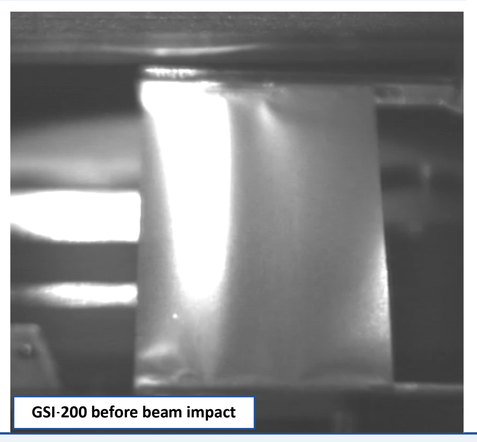
**Beam Characteristics for testing**

*Pulses vary from 200 µs to 600 µs with 50 µs to 150 µs batches

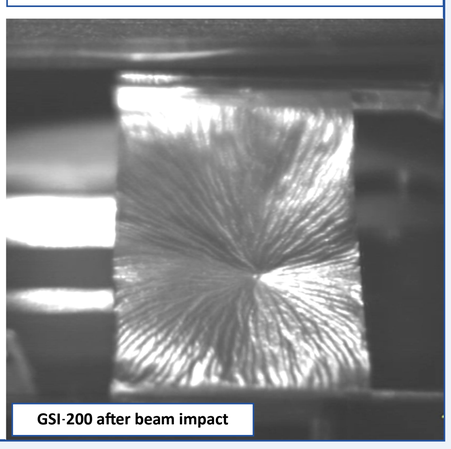






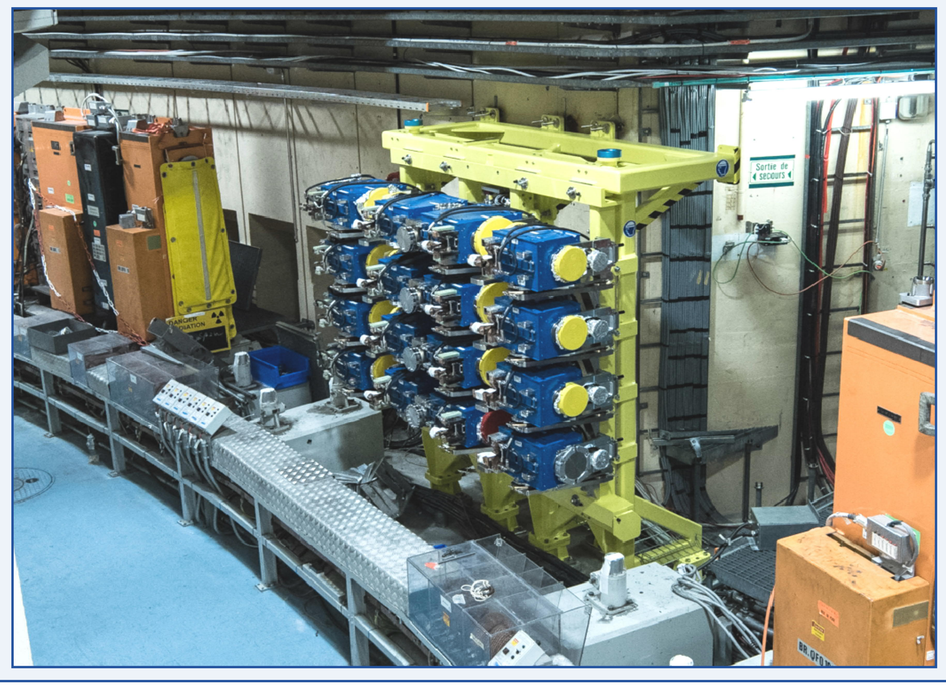



GSI-200 before beam impact



GSI-200 after beam impact

P+ Injection before LS2 modifications



## CONCLUSION

A complete new $H^-$ charge exchange injection system with chicane magnets, painting bump kickers, stripping foil mechanisms, internal beam dumps and dedicated instrumentation is installed in the 4 superposed PSB rings during LS2.

Also a stripping foil test stand is installed in the L4 transfer line and several types of foils have been evaluated, showing the expected theoretical efficiency >99%. For beam commissioning of the new PSB injection region, each type of tested foil will be installed in the exchange mechanism.